09 Oct 1975

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W. C. Wolkenhauer

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W. C. Wolkenhauer
Washington Public Power Supply System
Richland, Washington

Abstract

The effects of possible inadequate nuclear fuel reprocessing capability upon a public utility, Washington Public Power Supply System, are studied. The possible alternatives for storing spent fuel are reviewed.

1. INTRODUCTION

At present, there are no operating commercial nuclear fuel reprocessing plants in the U.S. Two plants are under construction and/or modification. According to present schedules, they would apparently be operating in time to receive spent fuel in the late 1970's. However, the owners of these plants are reluctant to contract for new business until such time as they better understand their costs, regulatory constraints, and construction schedules. Thus, it becomes necessary to examine the possible alternatives for storing spent fuel until reprocessing capability is available to nuclear electric utilities.

In this paper, the problem is examined from the standpoint of the Washington Public Power Supply System (WPPSS) nuclear plant construction and operation schedule. However, the analysis should be applicable to other possible utility systems. Some general conclusions are drawn which can be used to develop a general strategy leading to solutions to this problem.

2. DIMENSIONS OF THE PROBLEM

By examining the fuel management plans and proposed operating schedules for the WPPSS nuclear power plants, it is possible to project the nominal rate of discharge of spent fuel from the WPPSS reactors. The incremental and integral fuel discharge for each of the reactors is given in Table 1 for the decade of the 1980's. In addition, accumulated totals are given by year for the tandem units (i.e. WNP-3 & 5 and WNP-1 & 4).

In addition to the discharge schedule, the spent fuel storage capacity of the plants is needed in the analysis. WNP-2 has a nominal storage capacity of 1000 elements. WNP-1 and WNP-4 have storage capabilities of 288 elements each. WNP-3 and WNP-5 have spent fuel storage capabilities of 323 elements each. Typically, each spent fuel pool is designed to accommodate one full core plus an additional refueling batch, more or less. In the situation where refueling (and thus storage) is imperative, the requirement to be able to unload a full core at any time could be waived with the acceptance of some risk of forced shutdown.

Using the full capability of the spent fuel pool, the WNP-2 spent fuel pool as designed is filled to capacity in 1984. (Specifically, May 1 if present plans hold.) Similarly, the spent fuel pool of WNP-1 becomes full in 1984. The spent fuel of WNP-3 is full in 1985. The WNP-4 spent fuel pool becomes full in 1986 and the WNP-5 fuel pool becomes full in 1987. If the spent fuel pools of WNP-1 and WNP-4 are taken together, the pool of the combined facility is full in 1985. If WNP-3 and WNP-5 are taken together, their combined storage capacity is exhausted by 1986 (i.e., September 1, 1986). The actual date for mandatory shutdown for each plant extends one cycle beyond the above dates.

Storage of fuel from WNP-2 in the storage pits of the other reactors and vice versa could not be accomplished without radical redesign of the spent fuel racks of the other reactors because of dimensional differences between BWR and PWR fuel. Fuel storage between twin units is possible only if a fuel cask is available for the transfer and at some incremental risk of damage to the transported fuel assemblies.

The dimensions of the problem are clear. Assuming that spent fuel storage racks are incompatible for different fuel design types, and assuming that no reprocessing contract becomes available to the system, the capability to store WNP-2 fuel will be exhausted on May 1, 1984 and the total capability of the system as planned will be exhausted on September 1, 1986. Shutdown of WNP-2 would be mandatory on May 1, 1985 and the five planned reactors would be shut down on September 1, 1987.

In addition, the above dates assume that full core storage will not be required for maintenance and repair to the plant. There is a finite probability that shutdown could come much earlier. If WNP-2 were operated for its first two cycles and then be required to shut down during the third cycle for major maintenance requiring core removal, a stalemate situation would be reached in that the reactor could neither be unloaded or operated. Thus, any time after August 1, 1981, the potential for WNP-2 shutdown exists in the absence of either a reprocessing contract or expanded storage capability.

This review summarizes the situation with regard to the WPPSS nuclear power plants. Most probably, a similar situation exists for most electrical generating utilities with nuclear power plants. Clearly, a substantial amount of nuclear fuel will be available for reprocessing in the 1980's.

3. THE EFFECT OF THE NATIONAL SITUATION

One of the factors in determining the viable options available to a nuclear utility in the event it cannot obtain a fuel reprocessing contract is the probable situation with regards to the rest of the nuclear power industry during the next 20 years.

The national situation does not necessarily dictate the action that a utility might take. Even in a time of reprocessing capacity shortage, some organizations will obtain a reprocessing contract (probably at premium rates). However, the more dismal the national situation, the smaller the chance becomes that a given utility will obtain a reprocessing contract. Therefore, this discussion is intended to give some context to and set the stage for a discussion of alternatives in the event that a utility does not obtain a reprocessing contract.

A number of predictions have been made of

TABLE 1

Accumulation of Spent Fuel
From WPPSS Nuclear Power Plants

Nuc. Pow. Plant / Year	WNP-2 Fuel Ele. Disch.	WNP-1 Fuel Ele. Disch.	WNP-3 Fuel Ele. Disch.	WNP-4 Fuel Ele. Disch.	WNP-5 Fuel Ele. Disch.	WNP-2 Acc. Disch.	WNP-1 Acc. Disch.	WNP-3 Acc. Disch.	WNP-4 Acc. Disch.	WNP-5 Acc. Disch.	WNP-1 WNP-4 Acc. Disch.	WNP-3 WNP-5 Acc. Disch.
1980	168					168						
1981	164	69				332	69				69	
1982	184	68	72			516	137	72			137	72
1983	184	68	80	69		700	205	152	69		274	152
1984	208	69	81	68	72	908	274	233	137	72	411	205
1985	216	68	80	68	80	1124	342	313	205	152	547	465
1986	212	68	84	69	81	1336	410	397	274	223	684	630
1987	212	69	85	68	80	1548	479	482	342	313	821	795
1988	212	68	84	68	84	1760	547	566	410	397	957	963
1989	212	68	84	69	85	1972	615	650	479	482	1094	1132
1990	212	69	85	68	84	2184	684	735	547	566	1231	1301

the rate at which nuclear power will be introduced in this country.[1] In federal reports, these predictions are labeled A through D, ranging from C being the highest rate of introduction, then B, then D, and finally A as the lowest rate. These rates can be translated on a yearly basis into projected reprocessing loads. In this analysis, rates B (high intermediate) and D (low intermediate) are considered.

The national reprocessing load, in metric tons per year (MT/Y) for rates B and D is shown in Table 2. Additionally, there are a number of possible scenarios which can be defined which specify the rate at which reprocessing capability might be added in this country. A number of scenarios (labeled B through H) are defined during the course of this analysis. The specific scenarios used are listed in Table 3.

In table 3, scenario B is the currently anticipated rate at which reprocessing capacity will be added to the system. In the other scenarios, delays and cancellations of Plants #2 (AGNS), #3 (NFS), and #4 (EXXON) are envisioned. Changes in the schedule (i.e., delays or cancellations) of Plants #5 and beyond are not of interest to this analysis as we wish to assess the situation in the 1980's. Additionally, adding capacity beyond that now planned seems unrealistic for the time period 1975-1983, as it apparently takes about as long to build and license a reprocessing contract as it does a reactor.

Considering first the nuclear plant startup Schedule D (assumes some delays from the 1974 nominal), Figure 1 displays the quantity of spent fuel which must be stored in any given year from 1974 to 1994 for the present planned situation (scenario B), delay of Plant #3 (NFS) by two years (scenario D), and cancellation of Plant #3 (scenario C). If the nominal situation comes true, a utility with plants coming on line in the 1980's will not be affected materially as the problem is solved by 1983. If the NFS Plant is delayed two years, a national storage problem exists until 1987 and if the NFS Plant is cancelled, a national problem exists until 1994.

Figure 2 displays the impact of delay or cancellation of Plant #2 (AGNS). Delay of AGNS for two years results in extension of the storage problem to 1987, just as in delay of the NFS plant, but the fuel storage requirements are somewhat larger (i.e., a peak of 4650 MT vs. 3450 MT). Cancellation of AGNS creates a major national storage problem of up to 14100 MT of spent fuel until the year 1997.

Figure 3 shows the effect of delay or loss of Plant #4 (scheduled to start up in 1983) on the requirement for storage of spent fuel. Because this plant comes into the system later, its impact is felt later. A delay of two years results in a requirement for storage out to the year 1990 with a storage peak of 5200 MT in 1984. Loss of the 1983 plant results in a requirement for storage until the year 2000 with a required storage peak of 21600 MT in 1992.

In order to estimate the effect of delays or speedup of nuclear power plant construction on the nominal spent fuel storage requirements, the storage requirements for scenario B (nominal) are shown in Figure 4 for two nuclear power plant construction schedules (B - high intermediate and D - low intermediate). The major effect of changing the initial nuclear power plant construction schedule on spent fuel storage requirements, given the present planned reprocessing plant construction schedule, seems to vary the peak requirements for storage (i.e., 3300 MT for Schedule B vs. 2500 MT for Schedule

TABLE 2

SPENT FUEL REPROCESSING LOAD FOR NATION

Year	Schedule B MT/Y	Schedule D MT/Y
1970	51	
1971	85	
1972	147	
1973	229	4
1974	367	0
1975	567	250
1976	814	930
1977	1080	1310
1978	1300	1710
1979	1500	1660
1980	1730	1740
1981	2050	2300
1982	2550	3000
1983	3190	3700
1984	3820	4300
1985	4490	4800
1986	5270	5600
1987	6090	6200
1988	6950	7000
1989	7870	8100
1990	8860	8900
1991	9910	9900
1992	11000	11000
1993	12100	11900
1994	13100	13000
1995	14400	14000
1996	15500	14900
1997	16500	15800
1998	17500	16800
1999	18400	17500
2000	19400	18300

TABLE 3

REPROCESSING PLANT ADDITIONS

Plant No.	Owner	Capacity (MT/Y)
1	General Electric (GE)	300
2	Allied General Nuclear Services (AGNS)	1500
3	Nuclear Fuel Services (NFS)	750
4	EXXON*	3000
5	-	3000
6	-	3000
7	-	6000
8	-	6000
9	-	6000

EXPLANATION OF SCENARIOS

Plant No.	B	C	D	E	F	G	H
1 (GE)	----	----	----	----	----	----	----
2 (AGNS)	1978	1978	1978	1978	1978	<u>1980</u>	<u>----</u>
3 (NFS)	1978	<u>----</u>	1980	1978	1978	1978	1978
4 (EXXON)	1983	1983	1983	<u>1985</u>	<u>----</u>	1983	1983
5	1987	1987	1987	1987	1987	1987	1987
6	1990	1990	1990	1990	1990	1990	1990
7	1993	1993	1993	1993	1993	1993	1993
8	1997	1997	1997	1997	1997	1997	1997
9	2000	2000	2000	2000	2000	2000	2000

* Most Propable Owner (Not Announced)

---- Plant Cancelled

—— Change from Nominal

FIGURE 1 EFFECT OF LOSS OR DELAY OF EFS PLANT

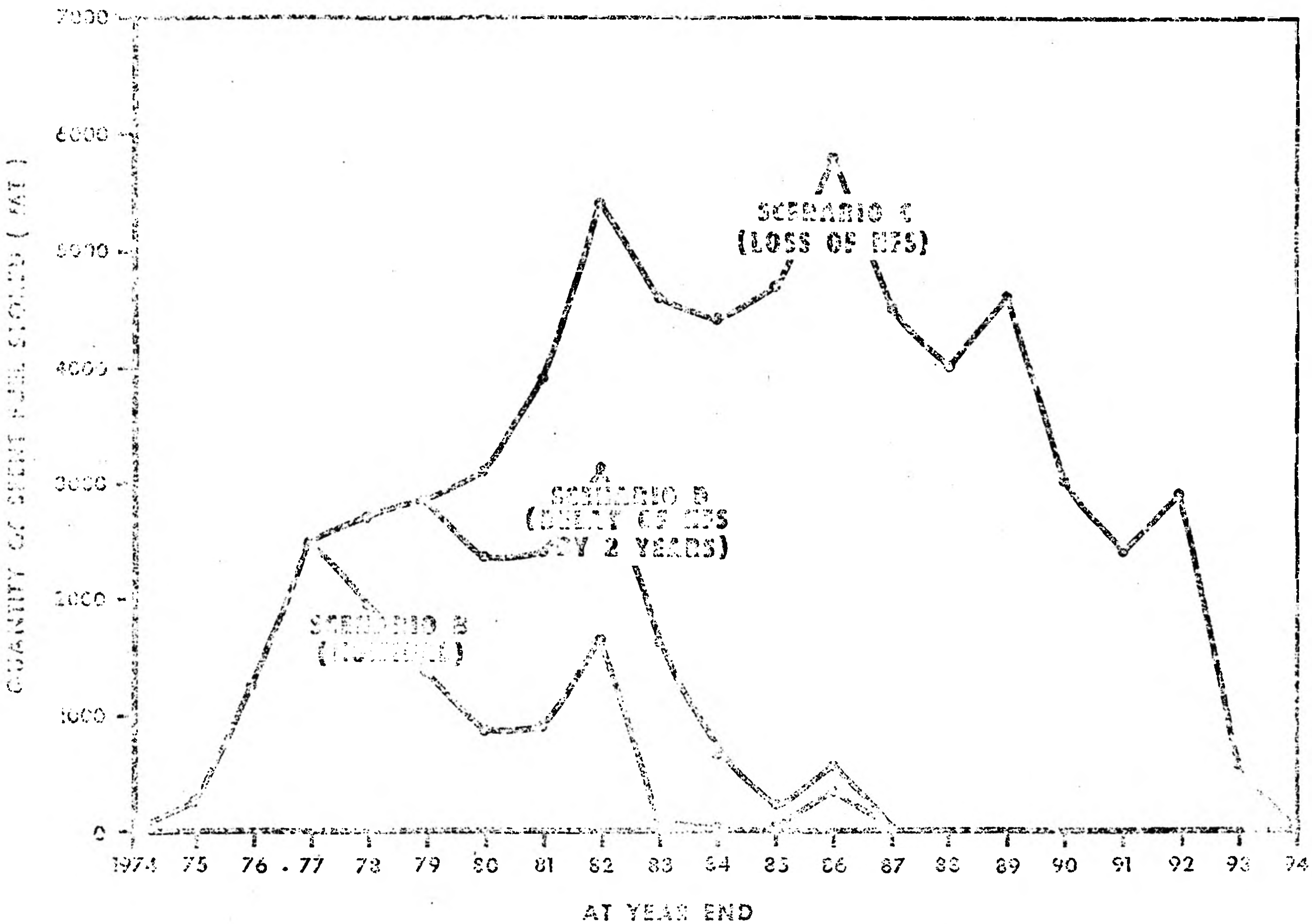
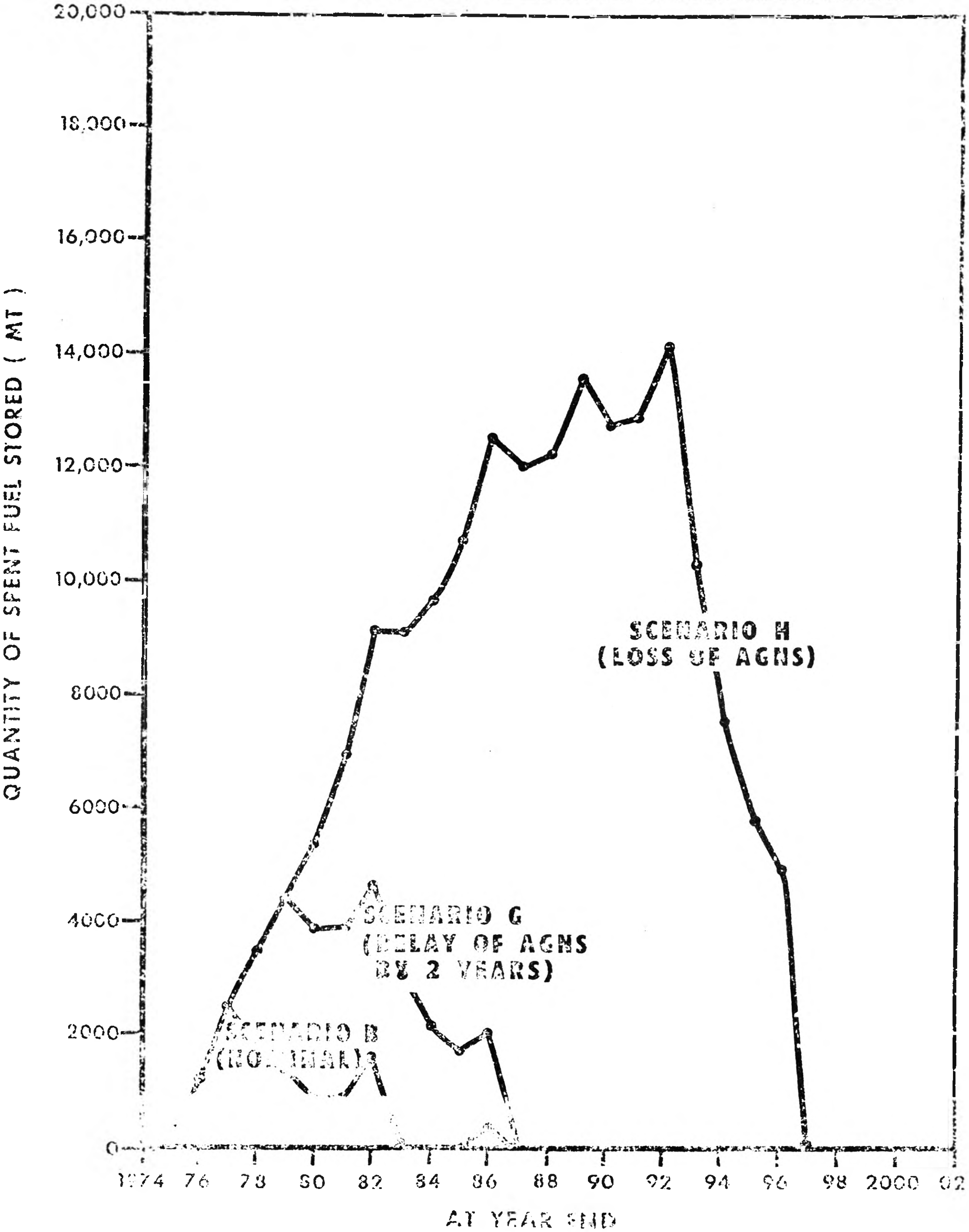


FIGURE 2 EFFECT OF LOSS OR DELAY OF AGNS



C). The peak year is still 1977 and the problem persists to some extent through 1983 independent of the nuclear power plant construction schedule.

A number of conclusions can be drawn from this analysis of the national situation. They are:

(1) If the nominal schedule for future reprocessing capacity additions holds, there will be sufficient reprocessing capability for the nation beyond 1983.

(2) Any deviation from the nominal schedule could result in the need for a utility to expand, build or lease storage space for several years, starting in 1983. Certainly, the likelihood of a utility obtaining a contract for reprocessing services would be greatly decreased.

(3) Changes in the construction schedule for nuclear power plants are not likely to affect the above conclusions.

(4) The spent fuel surplus in the 1980's cannot be materially changed by adding an additional reprocessing plant unless it can be built before 1983 (which is extremely unlikely).

(5) If storage facilities are built, a minimum payoff period of five years seems justified, based on the length of likely periods of a national deficit in reprocessing capability.

In addition to the above conclusions, a key question that must be considered is the likelihood that Plant #4 (Exxon) will be available in 1983. This plant has not as yet been announced. A review of Figure 3 shows that a nominal delay of this plant would assure a captive reprocessing market whereas introduction in 1983 results in a slight industry surplus of reprocessing capacity. Conversely, a captive market could result in utilities building storage facilities. Once built, they would be integrated into fuel management plans so that utilities might tend to delay reprocessing in order to achieve (hopefully) cheaper reprocessing rates.

To analyze this question, Figure 5 displays the results of the nominal schedule (scenario B) with and without Plant #1 (G.E.). The latter curve represents the situation which existed when the present plants were committed. This curve shows that cancellation of Plant #1 did not materially affect the present situation. Additionally, it shows that the reprocessing industry was slow in planning additions compared to demand. This could be attributed to lack of anticipation in the 1960's of nuclear growth in the 1970's, or it could be construed as delay in order to be assured of a market. In any case, based on the present and past conditions, delay of the 1983 plant for business reasons does not seem unrealistic.

In summary, the present situation is not catastrophic with regard to nuclear utilities. However, a utility should be reviewing its options in the event of delays of Plants #2 (AGNS), #3 (NFS) and #4 (1983) and should exercise one or more of these options if any delays seem likely.

4. CONSTRUCTION OF SEPARATE SPENT FUEL STORAGE FACILITIES

With regard to construction of separate spent fuel storage facilities, the USAEC apparently considers this a probable short-term reality. The USAEC has recently issued Regulatory Guide 3.24, "Guidance on the License Application, Siting, Design and Plant Protection for an Independent Spent Fuel Storage Installation" (December 1974). The licensing procedure is similar to that for a nuclear power plant. The installation is conceived of having a minimum capacity of 1000 metric tons (MT) of spent fuel (3200 BWR elements). A typical nuclear power plant discharges about 30 MT of spent fuel per year.

[illegible] DELAY OF 1983 [illegible]

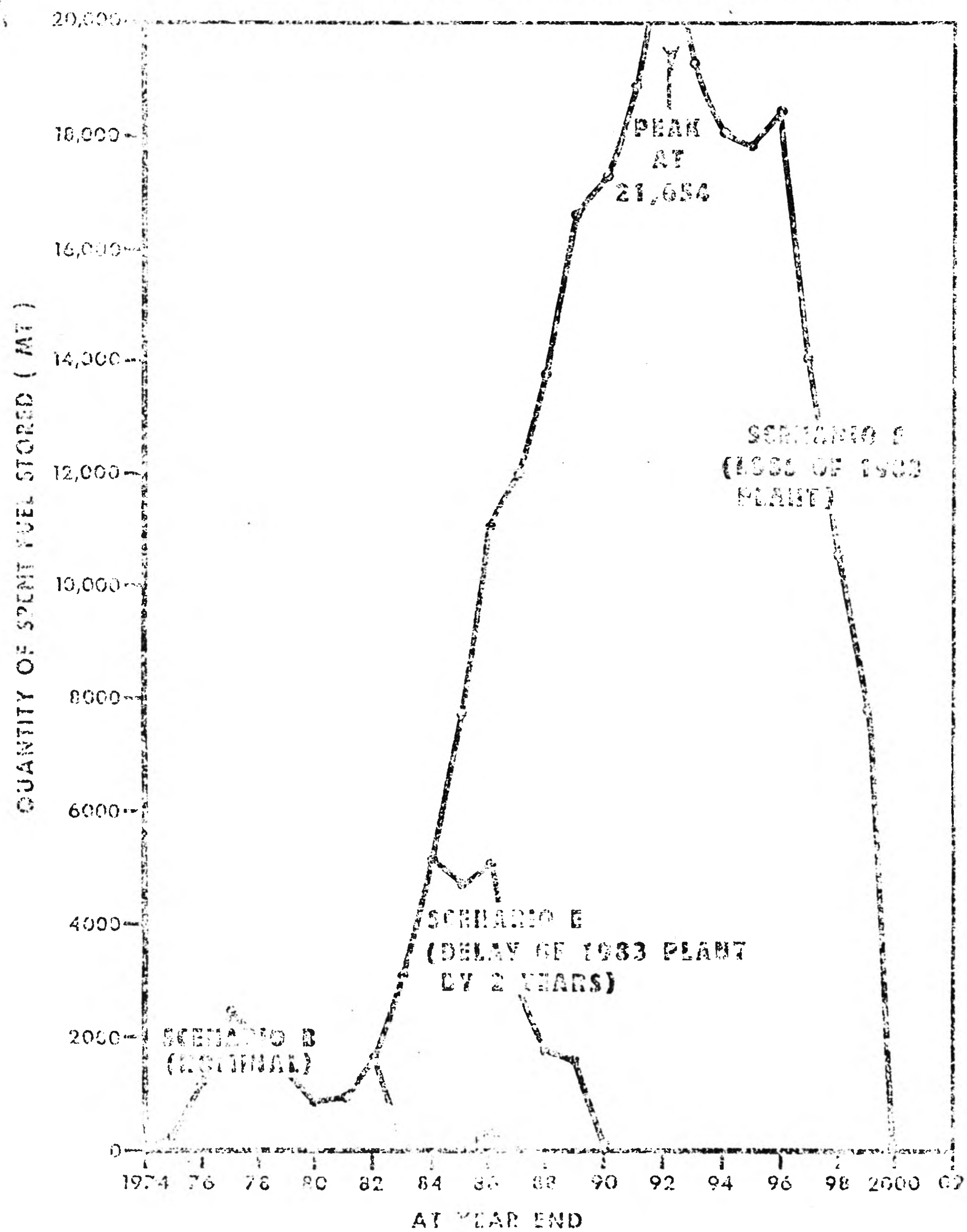


FIGURE 6 EFFECT OF DELAY OF [illegible] PLANT STARTUP
SCENARIO B (NOMINAL)

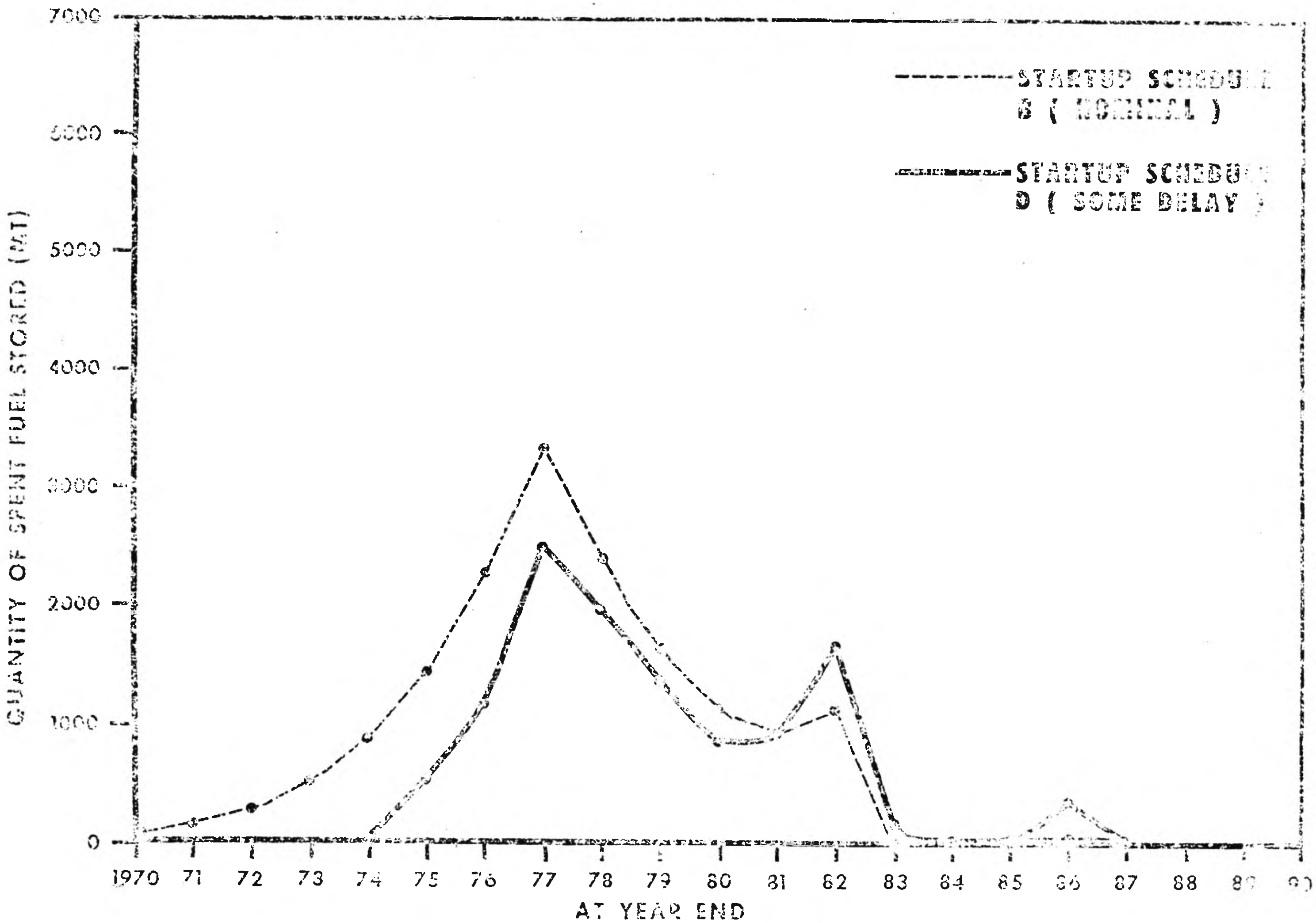
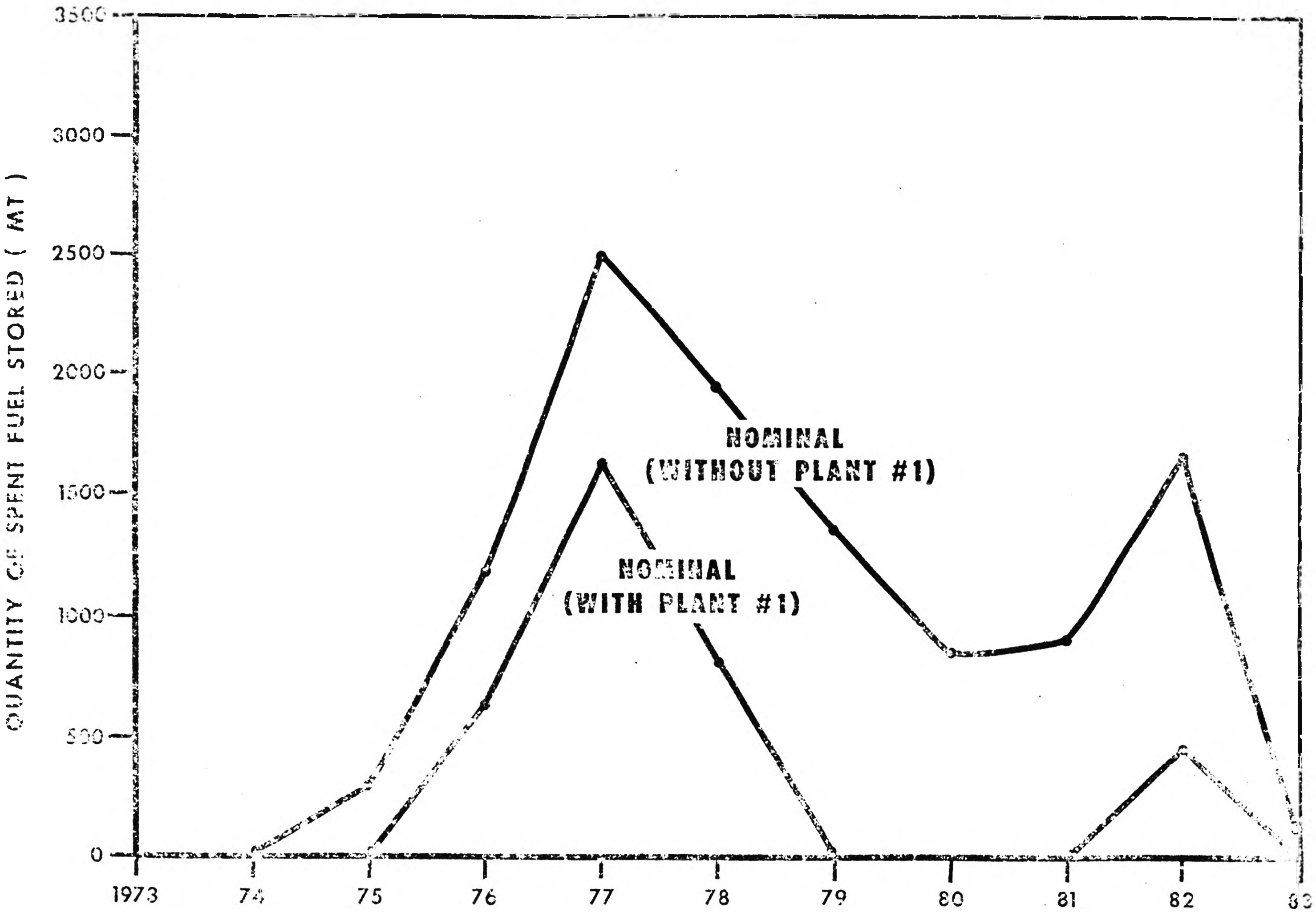


FIGURE 5 STORAGE REQUIREMENTS FOR NOMINAL REPROCESSING PLANT CONSTRUCTION SCHEDULE WITH AND WITHOUT PLANT # 1 (G.E.)



A 1000 MT storage facility with a 15-year payoff has been estimated to cost 20 million dollars. Assuming linearity, a 3000 MT storage facility would then cost 60 million dollars. Assuming an interest rate of 6%, this would result in an average storage charge based on capital return of $4,500 per MT per year. The cost would be lower if it were filled faster. This rate reflects the fact that the facility is partially empty for most of its life. At an interest rate of 14%, the average storage charge based on capital return would be $7,500 per MT per year. I arbitrarily assume a value of $1,000 per MT per year for facility operating costs. If this is the case, at an interest rate of 6%, the storage charge would be $5,500 per MT per year and at an interest rate of 14%, the storage charge would be $8,500 per MT per year. In addition to the above storage charges, there would be a transportation charge per metric ton of fuel which accrue to that fuel which must be shipped to the storage facility. I estimate this cost to be $8,800 per MT with no escalation for at least one typical situation. The average cost with escalation would be $12,300 per metric ton. Considering the total storage bill for the 15-year time period, the transportation charge is small in comparison.

5. LEASE/STORAGE

Renting of storage space for spent fuel may prove to be attractive. Factors which need to be evaluated include possible high incremental transportation costs, possible high rental charges due to incentives for early cost recovery on the part of entrepreneurs, and questions of ultimate responsibility.

General Electric Company has proposed construction of a separate $25,000,000 storage facility in addition to expansion of the storage capacity of its Morris, Illinois, installation. In addition, E. R. Johnson Company, in collaboration with Merrill, Lynch, Pierce, Fenner, and Smith, Inc., has proposed construction of a 1000 MT storage facility. This facility is estimated to cost 20 million dollars. Space would rent in this facility at the rate of $10,000 per MT per year. The location of the facility is unspecified.[2]

The sponsors justify this charge by asserting that the equivalent cost of storing the plutonium contained in a MT of spent LWR fuel would amount to $20,000 per MT of spent fuel if the plutonium were separated during reprocessing and not recycled but stored.

There are approximately 10 reactors which could utilize this facility immediately. Assuming a discharge of 30 MT per reactor per year means that 10 reactors would fill this facility in three years. Assuming a design life of 15 years for the facility and assuming that it fills at the above rate, the rental charge amounts to a return on capital excess of 35%, if the operating cost is taken as $1,000 per MT per year. Viewed another way, assuming an interest charge of 14%, this facility would be paid for in less than five years with the storage charge of $10,000 per ton per year. If the facility were filled as soon as completed, the facility would be paid for in about three years with this storage charge. Assuming that this facility could be built by 1980 but not before, a five-year payoff period is generally consistent with the present situation (Figure 1-Scenario B). Any delays would result in substantial profit to the owners.

As with owned storage space, there would be a transportation charge associated with shipment of the fuel to the storage facility. I assume that the transportation distance would be 2,000 miles and therefore I assign a transportation charge of $50,000 per metric ton to the fuel. If the storage facility were located near an eventual fuel reprocessing facility, this transportation charge could then be pro-rated, on some basis, to both storage and reprocessing.

6. IMPACT OF DELAYED REPROCESSING ON NUCLEAR FUEL COSTS

The calculations in this analysis were performed with the Hanford Fuel Cost (HFC) code developed by Omberg.[3] The calculations were performed using the WNP-2 reactor characteristics as input. A twenty-four cycle calculation was performed in order to assure that the reactor was on an equilibrium fuel cycle. In general, unless noted otherwise, a 6% interest rate was used in the analysis.

During the course of performing the analysis, two significant changes were made to the code by D. H. Thomsen. One change delayed reprocessing until a date which is specified as input. At this date, all fuel which has been delayed is reprocessed and credited to the appropriate batch (weighted by a present worth factor). Fuel discharged after this date is reprocessed in the normal manner. The second change allowed for input of a fuel storage charge (in $/Kg U) for the fuel which was delayed.

The first step in the analysis was to calculate the impact of the reprocessing delay alone on fuel cycle costs without computing the accompanying cost of fuel storage. The major costs of delaying reprocessing are the costs of additional fuel and storage of the spent fuel. By separating these costs, it is possible to identify the important cost parameters in the problem.

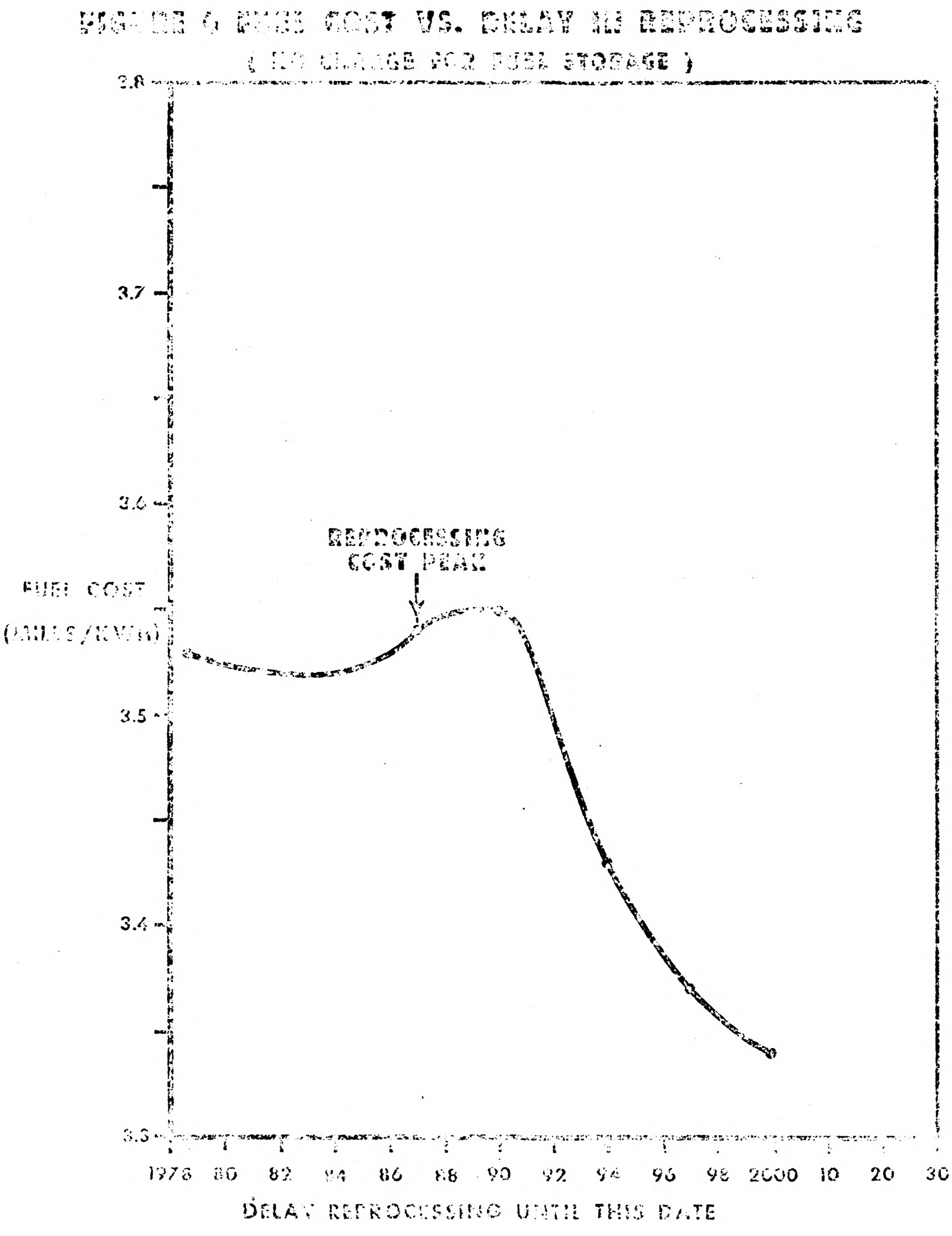
Figure 6 shows the levelized fuel cost for WNP-2 as a function of reprocessing delay. The costs reflect the additional fuel which must be purchased but do not, in this figure, reflect the storage costs.

Figure 6 starts with a base case (no reprocessing delay) fuel cost of 3.53 mills/kwh. The fuel cost drops slightly before rising to a maximum of 3.55 mills/kwh in 1990. From 1990 until 2000, the fuel cost drops rapidly to 3.34 mills/kwh. No analysis was performed for the years beyond 2000. The relatively rapid drop in fuel costs beyond 1990 is attributed to the predicted cost structure used in this analysis. As noted on Figure 6, the cost of enrichment used in this analysis peaks in 1987 and then drops substantially over the period of interest. Fuel fabrication and uranium costs continue to rise over the total period. The plutonium price escalates until the year 2000 and is assumed stable beyond 2000. Thus, this curve shows that, for the price and particularly the enrichment price structure shown, it is cheaper to store fuel and buy extra enrichment than it is to reprocess the fuel if the price of storage is zero.

It has been shown that the drop in fuel cost curve caused by a reprocessing delay is temporary. Delaying reprocessing essentially forever results in a fuel cost of 4.32 mills/kwh.

To obtain perspective, the base case was run at 12% interest rather than 6% interest. The resulting levelized fuel cost was 3.76 mills/kwh. Thus, changes in interest rate overshadow all the fuel cost changes shown in Figure 6.

In this portion of the analysis, the previous calculations were performed with the addition of a cost for storage of the fuel. Costs were used which reflect the cost, both in WPPSS-owned facilities and rental of storage space in facilities owned by others. Specifically, a charge of $5,500 per metric of fuel ton per year of fuel



REPROCESSING COST PEAK
FUEL COST (MILLS/KWH)
3.8
3.7
3.6
3.5
3.4
3.3
1978 80 82 84 86 88 90 92 94 96 98 2000 10 20 30
DELAY REPROCESSING UNTIL THIS DATE

was used for WPPSS-owned facilities and a charge of $10,000 per metric ton of fuel per year was used for rented facilities.

Figure 7 shows the levelized fuel cost for 24 cycles for WNP-2 as a function of reprocessing delay assuming a storage charge of $5,500 per metric ton of fuel per year.

Comparing Figure 7 to Figure 6 shows that the cost of storing the spent fuel is the major cost item in delaying reprocessing. In Figure 7, the fuel cost peak at 1990 is located at the same time point as in Figure 6, but the peak is higher (3.61 mills/kwh as 3.55 mills/kwh) and the minimum in the year 2000 is 3.49 mills/kwh rather than 3.34 mills/kwh as in Figure 6. A study of Figure 7 also indicates that if fuel is to be stored, it is advantageous to store it for a considerable length of time (i.e., beyond 1990). This is probably due mostly to the enrichment price structure described previously. Another conclusion that can be tentatively drawn from Figure 7 is that the decision on whether or not to store fuel will probably be made on the basis of other parameters than fuel costs as the variations shown in Figure 7 are probably within current calculational uncertainties and, in any case, are considerably overshadowed by such parameters as the interest rate.

7. SUMMARY

It has been shown that there is a strong possibility that utilities will be forced to delay reprocessing of spent fuel from their nuclear power plants due to a shortfall in reprocessing industry capacity which is likely to exist well into the 1980's. In this analysis, some preliminary calculations have been done to assess the impact of this delay on nuclear fuel costs. The specific calculations were performed on the WNP-2 nuclear power plant but the conclusions drawn from the results are expected to be generally applicable to other nuclear power plants.

On the basis of this analysis, a number of conclusions have been drawn. They are:

(1) The major change in the fuel cost which results from delay in reprocessing spent nuclear fuel is the cost of storing the spent fuel.

(2) The cost of additional uranium and enrichment requirements is not substantial.

(3) For the specific reactor analyzed, the levelized fuel costs rise if a short storage period is used, but ultimately decrease with long-term (i.e., 10 years) storage. Therefore, if reprocessing is delayed, storage of spent fuel for time periods greater than 10 years is preferred.

(4) The changes in levelized fuel costs due to storage are small compared to other uncertainties. Under certain conditions, a small decrease in levelized fuel costs can be realized by temporary storage of spent nuclear fuel.

8. BIOGRAPHY

Mr. W. C. Wolkenhauer is a nuclear engineer with the Washington Public Power System. Prior to that he worked at Battelle-Northwest Laboratory and at the LaCrosse Boiling Water Reactor.

He received his B.S. from Carroll College in 1961 and his M.S. from Missouri School of Mines in 1962.

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2. Nucleonics Week, August 22, 1974.
3. R.P. Omberg, "A Model for Calculating the Incremental Fuel Cost of Reactor Operating Strategies," Hanford Engineering Development Laboratory, September 17, 1974, Richland, Washington.

FIGURE 7 FUEL COST VS. DELAY OF REPROCESSING
FOR A STORAGE CHARGE OF [illegible]/METRIC TONNE / YEAR